DOCUMENT RESUME

ED 189 442 CE 026 101

TITLE Electrical Experiments. VT-214-12-5. Part V. Transformers.
INSTITUTION Connecticut State Dept. of Education, Hartford. Div. of Vocational Education.
PUB DATE [77]
NOTE 59p.: For related documents see CE 026 095-102.

EDRS PRICE MF01/PC03 Plus Postage.
DESCRIPTORS *Electrical Occupations: Electrical Systems: *Electricity: Learning Activities: Secondary Education: *Vocational Education
IDENTIFIERS *Transformers

ABSTRACT

Designed for high school electronics students, this fifth document in a series of six electrical learning activity packages focuses on transformers. An introductory section gives the objective for the activities, an introduction, and an outline of the content. The remainder of the activity book is comprised of information sheets and job sheets on topics such as (1) polarity of transformers and (2) three-phase connections. Each job sheet follows a typical format that includes the objective, materials, explanation, procedure, and evaluation questions. (LRA)

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ED189442

CONNECTICUT STATE DEPARTMENT OF EDUCATION

DIVISION OF VOCATIONAL EDUCATION

HARTFORD

ELECTRICAL EXPERIMENTS

VT - 214 - 12 - 5

PART V

TRANSFORMERS

CE 026 101

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
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TRANSFORMERS

Contents

	No. of Pages
General Information - Transformers	5
Information Sheet 1 - Polarity of Transformers	4
Job Sheet 1 - Connecting Single Phase Transformers	3
Job Sheet 2 - Checking Polarity of Transformers	4
Job Sheet 3 - Connect Transformers in Parallel	3
Job Sheet 4 - Connect Single Phase Transformers for 3 Wire System	3
Job Sheet 5 - Connect Single Phase Transformers in Series	1
Job Sheet 6 - Short Circuit Test on Transformers	4
Job Sheet 7 - Core Test on Transformers	3
Job Sheet 8 - Two Phase Transformer Scott Connection	2
Information Sheet 9 - Three Phase Connections	6
Job Sheet 9-A - Open Delta to Open Delta	2
Job Sheet 9-B - Closed Delta to Closed Delta	2
Job Sheet 9-C - Open Delta to Open Delta 4 Wire	1
Job Sheet 9-D - Closed Delta to Closed Delta 4 Wire	2
Job Sheet 9-E - T Connection to T Connection 4 Wire	3
Job Sheet 9-F - Wye to Wye	2
Job Sheet 9-G - Delta 3 Wire to Wye 4 Wire	2
Job Sheet 9-H - Wye to Delta	2
Job Sheet 9-I - Grounding of Electrical Equipment (Auto Transformer)	2

TRANSFORMERS

General Information
Page 1 of 5

A transformer is a device by which alternating voltages may be stepped up or down as desired. Another important use for a transformer is for isolating circuits from ground potentials.

It is necessary to use high voltage in order to transmit large amounts of electrical power economically over long distance lines.

Power losses in lines are directly proportional to the resistance of the lines and to the square of the current that flows through the lines. ($P = I^2R$)

Since power in any circuit is equal to the product of voltage and current ($P = E \times I$), it is easy to see that the larger the voltage, the less current is needed to transmit a particular amount of power.

EXAMPLE: P equals Voltage times Amperage

100 volts times 100 amps equals 10,000 watts

1000 volts times 10 amps equals 10,000 watts

10,000 volts times 1 amp equals 10,000 watts

It is easy to see that at a larger voltage less amperage is needed. With less amperage in a circuit, smaller power lines are needed. Poles and towers for lines may be smaller and separated more. Line losses will be much less for high voltage, low amperage circuits than they would be if low voltage, high amperage circuits were used.

EXAMPLE: P equals I^2R.

Assume a line with a resistance of 2 ohms with different amps.

POWER LOSS 100 x 100 x 2 equals 20,000 watts of lost power

10 x 10 x 2 equals 200 watts of lost power

1 x 1 x 2 equals 2 watts of lost power

If power losses can be kept to a minimum, there will be more power where it is needed. In other words power losses in a line cause heat and waste energy. This is a voltage loss and there is less voltage where it is needed.

Transformers are one of the most efficient pieces of electrical equipment there is. Since there are no moving parts, large transformers have an efficiency of up to 90%.

Power transformers are often referred to as STATIC TRANSFORMERS, even though they have nothing to do with static electricity. The term is used because there are no moving parts.

Types of Transformers

A transformer consists of an iron core which provides a path for the magnetic flux and a base for which two windings are placed. The winding that is connected to the supply voltage is called the PRIMARY winding, and the winding going to the load is called the SECONDARY winding. This winding receives its power from the primary winding by induction and is connected to the load always.

There are several common types of transformers and they are classified according to the way their cores are constructed. They are known as core type, shell type, and distributed type. It is easy to remember the different types of transformers if you remember that a core type as only one magnetic path, a shell type as two magnetic paths and the distributed type as three or four magnetic paths.

Transformer Construction

The purpose of the transformer core is to provide a low reluctance path for magnetic flux. Transformer cores are made of a special grade of soft iron or silicon steel and are built up of thin laminations. These laminations are insulated from each other, either by a coating of insulating varnish or by an oxide scale which is formed on the surfaces by a heat-treating process.

This laminated construction reduces eddy currents which would be set up by the alternating flux and would cause the core to overheat.

When the core of stacked laminations are of the right shape for the particular transformer, coils of insulated wire are wound on the cores. These coils, insulated from each other, are the primary and secondary windings.

A transformer with more turns of wire on the primary than the secondary will cause a lower voltage in the secondary. There is a definite relationship between the number of turns in the windings and the voltage that is produced.

RULE: THE VOLTAGE ON THE COILS OF A TRANSFORMER IS DIRECTLY PROPORTIONAL TO THE NUMBER OF TURNS ON THE COILS.

$$\frac{E_p}{E_s} = \frac{N_p}{N_s}$$

TRANSFORMER TYPES

Types of Transformers

There are many types of transformers in use today. Each type is designed and best suited for a particular use. They vary not only in physical characteristics, as size and shape, but in electrical characteristics and efficiency as well.

The two broadest types of transformers are the iron-core and the air-core transformers. They obtain their name from the materials between the primary and secondary windings through which the flux lines pass. The windings of air core transformers are wound around insulated forms. Since the efficiency of air as a conductor of flux lines is not as good as iron cores the maximum efficiency is only about 65%. Generally air cores are used at high frequencies, where iron-core transformers are impractical because of the core losses.

Iron-core transformers have a core made of soft or powdered iron. The windings are wound around the iron core, and the flux lines travel through the core between the winds. A high degree of coupling is possible with such cores. To further improve the coupling, the primary and secondary windings are wound on top of each other, but insulated from each other. The coefficients of coupling is as high as 98% for good iron-core transformers.

The Autotransformer

An autotransformer is a transformer that physically has only one winding. A part of the winding is used as the primary, while the rest is used as the secondary. There is a common connection between the two coils. If all of the winding is used as the primary and only a part of the winding is used as the secondary, it is a step-down transformer. If part of the winding is used as the primary and all of it as the secondary, it is a step-up transformer. The turns ratio is still what governs the type of transformer.

A disadvantage of the autotransformer is the lack of isolation between the primary and secondary windings or circuit. This results from the primary and secondary both using some of the same turns. Despite this disadvantage, the autotransformer is used in a circuit because it is inexpensive.

Transformer Losses

In an ideal transformer the power in the secondary is equal to the power in the primary. This is not possible due to losses in the transformer itself. The efficiency of a transformer is the output power divided by the input power.

$$\text{Efficiency } (\%) = \frac{\text{output power}}{\text{input power}} \times 100$$

The smaller the output power in relationship to the input power the less the efficiency. Since transformer losses reduce the efficiency of a transformer and represent a loss of power they must be kept as low as possible.

Copper Loss and Leakage

Transformer windings are usually made of many turns of copper wire, and these windings have resistance. The more turns, the longer the wire is and the more will be resistance. When the primary and secondary currents flow through the windings, power is lost in the form of heat. These I^2R losses are called copper losses, and are proportional to the square of the current and of the resistance.

Hysteresis Loss

In an iron-core transformer, the core is magnetized by the magnetic field created by the current through the windings. The direction of the magnetic field that causes it to be magnetized. Each time the magnetic field around the winding expands and collapses, the direction in which the core is magnetized also changes.

When the core is initially magnetized, the molecules are aligned in the direction of the field. But when the magnetic field drops to zero, the molecules do not return to their original random orientations. As a result, although the magnetizing force has dropped to zero, the core still retains some of its magnetization. The magnetic field has to reverse direction and apply a magnetizing force in the opposite direction before the core returns to its unmagnetized state. The molecules are called hysteresis. The energy that has to be supplied to the molecules to cause them to turn around and, in effect, try to catch up with the magentic field, is called the hysteresis loss of the core. The more energy that is required, the greater the hysteresis loss.

Hysteresis Loop

Hysteresis losses depend mainly on the type of core material used. Materials that retain a large part of their magnetization after the magnetizing force is removed have high hysteresis losses. These materials are said to have high permanence.

For a given material, hysteresis losses are directly proportional to the frequency of the current in the transformer. The higher the frequency of the transformer, the more times per second the molecules of the core material must reverse their alignment; and so the larger is the total energy required for this purpose. The relationship between hysteresis loss and frequency is one of the main reasons why iron-core transformers cannot be used in applications involving high frequencies.

A hysteresis loop is a curve that shows how the magnetization of a material lags behind the magnetizing force. It can be used to indicate hysteresis loss. Point A corresponds to core flux in the positive direction. Since there is no magnetizing force, there is no core flux.

When the magnetizing force is first applied in the positive direction, the curve travels to Point B, which corresponds to core flux in the positive direction. When the magnetizing force drops to zero C, you can see there is still flux in the core in the positive direction. The magnetizing force has to reverse direction and reach point D before the material is demagnetized.

You can follow the remainder of the first cycle of the magnetizing force (D to E), and the complete second cycle (EFGBCDE), and see how the core magnetism lags behind the magnetizing force.

Eddy Current Loss

Since the iron core is a conducting material, the magnetic field of the transformer induces a voltage into the core. These currents are called eddy currents. Eddy currents act like short circuit currents and remove energy from the transformer windings and represent wasted power. Laminating the core helps to reduce these power losses.

The power losses due to eddy currents is proportional to both the frequency and amount of current in the transformer. Eddy currents and hysteresis limit the iron-core transformer to low frequencies.

Saturation Loss: An increase in current to the transformer after the core is saturated causes no increase in flux lines being produced, and only more wasted power.

Polarity of Transformers

Purpose:

To understand the term polarity as applied to transformers, single and three phase.

Explanation:

The term polarity as applied to a direct current generator, means that one terminal has a definite positive potential and the other a definite negative potential.

This definition, however, does not apply to a transformer, for a transformer is used on an alternating current circuit and each terminal is alternately positive and negative with each alternation of the applied voltage.

Polarity as applied to transformers, refers to a relative instantaneous polarity in the two windings.

POLARITY OF A SINGLE-PHASE TRANSFORMER

Let us consider the manner in which the winding is placed on the core form in Fig. 1. The heavy line A-B represents the low voltage windings, and the light line C-D the high-voltage winding. If a voltage is applied to either winding, a magnetic flux will be set up in the core which will link both windings and will therefore induce voltage in both, and since the winding from A to B goes around the core in the same directions as the winding from C to D, the voltage in both windings will be in the same direction. That is, A will be positive with respect to B at the same instant when C is positive with respect to D.

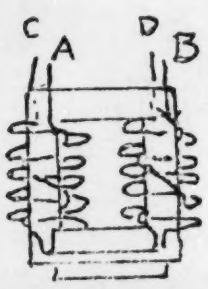


FIG. 1

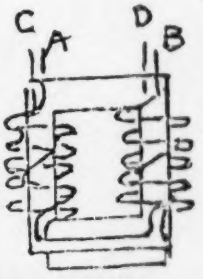


FIG 2

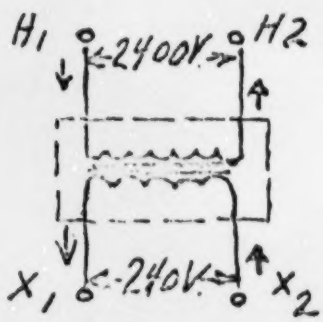
POLARITY OF SINGLE-PHASE TRANSFORMERS

If the direction of one of the windings around the core is reversed, as shown in Fig. 2, the flux in the core will induce voltages in opposite directions in the two windings. That is, A will be positive with respect to B at the instant C is negative with respect to D.

Polarity Markings

The ASA (American Standard Association) has developed a standard system of marking transformer leads. The high voltage winding leads are mared H_1 and H_2 and the low voltage winding leads are marked X_1 and X_2. The H_1 lead is always located on the left side when the transformer is faced from the low voltage side. When H_1 instantaneously positive X_1 will be instantaneously positive.

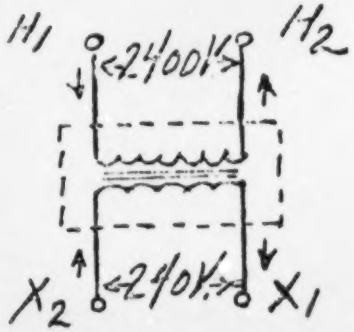
In Fig. 3, A and B are shown a subtractive polarity transformer and an additive polarity transformer.



SUBTRACTIVE POLARITY

FIG. 3a

MARKING OF TRANSFORMER



ADDITIVE POLARITY

FIG. 3b

A subtractive polarity transformer is one where the H_1 and X_1 leads are adjacent or directly across from each other. An additive polarity transformer is one where the H_1 and X_1 leads are diagonally across from each other.

The transformer leads are normally marked with identifying tabs or tags marked H_1 and H_2 and X_1 and X_2, etc. However the tags or markings may become lost or disfigured so that it is impossible to identify the various leads. Therefore, a standard test procedure has been developed to determine the identity of the leads.

Polarity Test

Fig. 4-a and 4-b show a test being conducted on an additive polarity transformer rated at 2400 V primary to 240 V secondary.

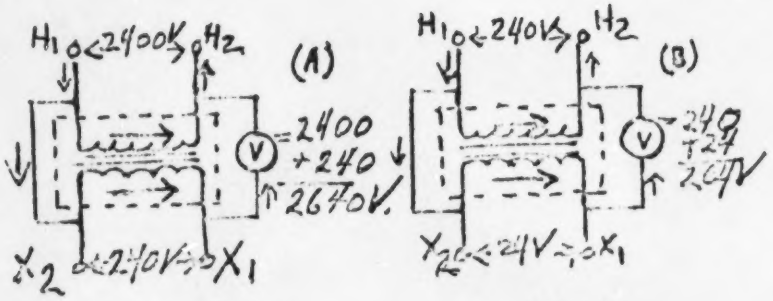


FIG. 4a FIG. 4b

TEST ON AN ADDITIVE POLARITY TRANSFORMER

In this test, a jumper lead is temporarily connected from the high-voltage lead H_1 to the low-voltage lead directly across from it. A voltmeter is connected from high-voltage lead H_2 to the low voltage lead directly across from it. If the voltmeter reads the sum of the primary input volts and the secondary volts which would be 2400 + 240 or 2640 volts, the transformer has additive polarity. When H_1 is instantaneously positive, 240 volts is induced in the secondary winding. The 2400 volts is applied to X_2 through the temporary jumper connections and adds to the 240 volts so that the potential difference, as indicated on a voltmeter connected from X_1 to H_2 is 2640 volts.

Because of the hazard involved in making this test at this high voltage, a realtively low test voltage is used to determine the transformer polarity. For example, in Fig. 4-b, 240 volts is used as a test voltage. This potential is usually available in the laboratory or repair shop and therefore, makes a convenient test source. With 240 volts impressed on the 2400 volt winding, 24 volts will be induced in the secondary winding of the transformer as the ratio is 10 to 1. The voltmeter connected across from H_2 to the low-voltage lead X_1 will now read 240 + 24 or 264 volts. Therefore, an A.C. voltmeter with a range of 0-300 volts can be conveniently used to determine the polarity.

The voltmeter connected from high voltage lead H_2 to the low-voltage lead directly across from it indicates the sum or addition of the primary or secondary voltages. A transformer with this type of polarity markings has additive polarity.

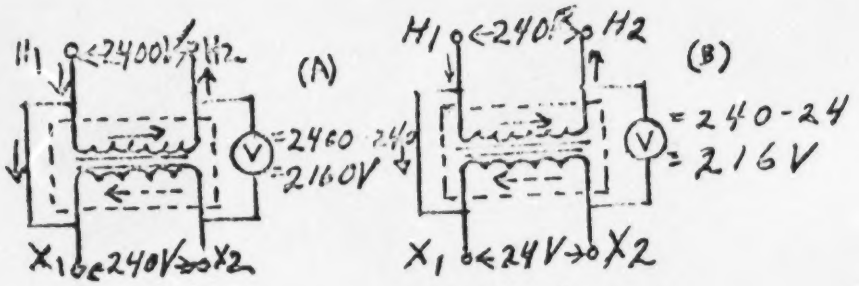


FIG. 5a FIG. 5b

TEST ON A SUBTRACTIVE POLARITY TRANSFORMER

Fig. 5a shows the same polarity test connections being used with a subtractive polarity transformer. The 240 volts induced in the secondary winding is opposing the 2400 volts entering X_1 from the temporary jumper connection. Therefore the voltmeter connected from H_2 to the low voltage lead X_2 will indicate a value of 2400-240 volts or 2160 volts. The polarity test Fig. 5b, uses a relatively low voltage, 240 volts. Here, the voltmeter indicates the difference or subtraction of the primary or secondary voltages which is 240 - 24 or 216 volts. A transformer of this type of polarity marking is said to have subtractive polarity.

The ASA (American Standard Association) and NEMA (National Electrical Manufacturers Association) have developed the following standards in reference to polarity of transformers:

1. Additive polarity shall be standard for all single phase transformers up to 200 kv-a and having voltage ratings not in excess of 9,000 volts.

2. Subtractive polarity shall be standard for all single-phase transformers larger than 200 kv-a regardless of voltage rating.

3. Subtractive polarity shall be standard for all single-phase transformers in sizes of 200 kv-a and below having high-voltage ratings above 9,000 volts.

In connecting single phase transformers in parallel or in a three phase bank, it is essential that the polarity of each transformer be known. Usually, this information can be obtained by checking the tag identification or the leads of, by checking the name plate. However, the standard polarity test procedure is often used to check the polarity if the polarity cannot be obtained otherwise.

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TRANSFORMERS

Job Sheet 1
Page 1 of 3

Connecting Single Phase Transformers

Objectives

(a) To acquaint the student with the different types of single phase transformers and connections.

(b) To understand the operation of the auto-transformer.

Explanation

The construction of a single phase transformer usually includes a core and at least two coils. The single phase auto-transformer actually uses only one coil.

A double wound transformer has essentially a primary and a secondary winding independent and insulated from each other.

Two popular arrangements of single phase transformer windings are shown in Fig. 1. Two single coils are used for step-down or step-up operation, such as bell ringing transformers, neon transformers, etc. Multiple coil primary and secondaries are used in distribution transformers where dual voltage ratings are desired. 2400 primary, 240-120 secondary, or 440-220 or 220-110 are possible connections.

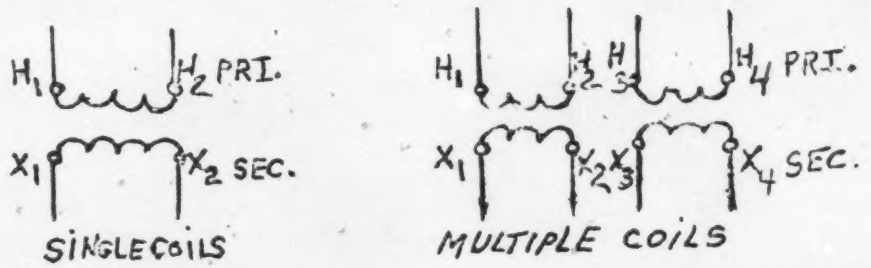


FIG. 1

Double wound transformers separate or insulate the high transmission voltages from the usual consumer voltage of 110-220-440. The NATIONAL ELECTRICAL CODE requires the use of this type of transformer in all distribution circuits, with the exception of those assigned to auto-transformers.

Single-Phase Transformer Connections

Series Connection

If 440/110/220 volts single-phase transformer is connected 440/220 volt, the two secondary coils must be connected in series.

The start and finish of each coil is joined, as shown in Fig. 2, 440/220V. All starts may be identified as odd numbered subscripts.

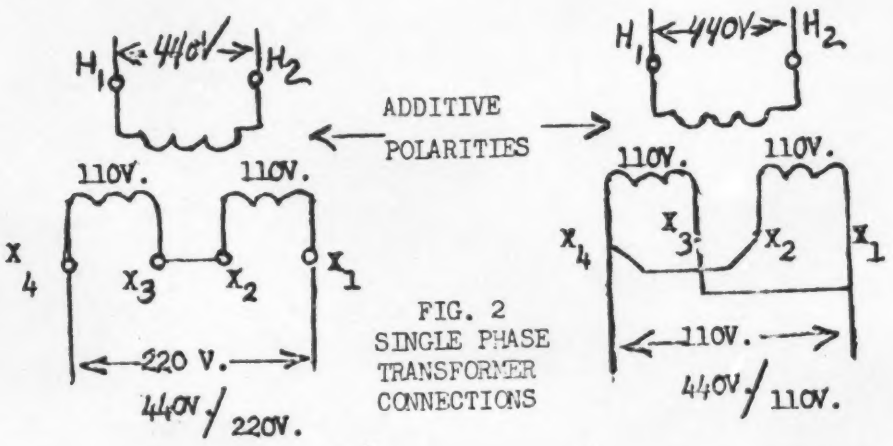


FIG. 2
SINGLE PHASE
TRANSFORMER
CONNECTIONS

Parallel Connections

The starts and finishes of the two secondary coils are joined, as in Fig. 2. It is important that the polarity of each coil is correct before making this connection. Parallel connection of two coils having opposite polarities will result in a short circuit causing internal damage to the transformer.

Parallel Operation of Single Phase Transformers

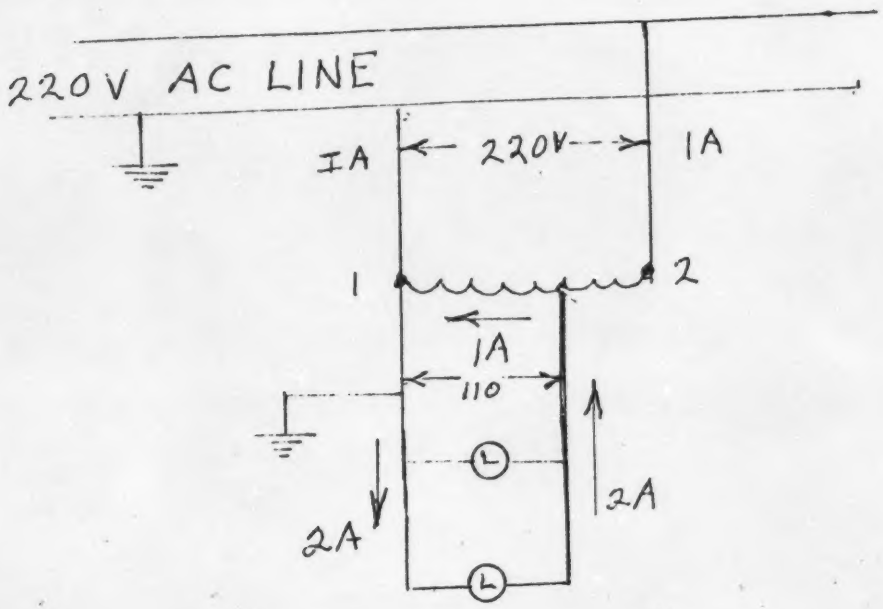
Single-phase distribution transformers can only be connected in parallel if the voltage and per cent impedance ratings are identical. It is wise to adhere to this rule for permanent parallel connections of all transformers. The load must divide in proportion to the respective transformer capacities.

Section 450-6 in the N.E.C. requires that transformers may be operated in parallel and switched as a unit provided that the overcurrent protection for each transformer shall not be set at more than 250 per cent of the rated primary current of the transformer.

Auto Transformers

Transformers having only one winding are called auto-transformers. This is the most efficient type of transformer since one winding is used instead of two, and a portion of the winding actually carries the difference between the primary and secondary.

Fig. 3 shows the current distribution in a practical situation. The great disadvantage of this transformer is the fact that the use of only one winding makes it impossible to insulate the low voltage from the high-voltage transmission line.



The National Electrical Code specifies that the use of auto-transformers be limited to the following:

1. Where the system supplied contains an identified grounded conductor which is solidly connected to a similar identified grounded conductor of the system supplying the auto-transformer.
2. Where an auto-transformer is used for starting or controlling an induction motor.
3. Where an auto-transformer is used as a dimmer as in theaters.
4. As part of a ballast for supplying lighting units.

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TRANSFORMERS

Job Sheet 2
Page 1 of 4

Checking Polarity of Transformer

Objective

To observe the various methods to determine polarity of a transformer.

To observe the current and voltage relationships between the high voltage and low voltage windings of a transformer.

Materials Required

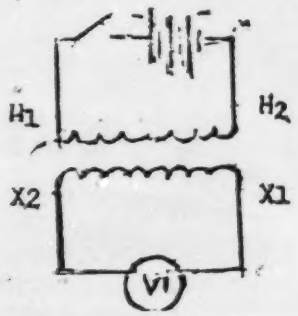
1 - Single phase transformer, 220/110 volt distribution type
1 - A.C. voltmeter 0-150-300 volts
1 - A.C. voltmeter 0-20 amperes
1 - A.C. voltmeter 0-10 amperes
1 - D.C. voltmeter 0-10 V
1 - Oscilloscope

Explanation

Read Information Sheet 2 "Polarity of Transformers" before conducting this job.

Procedure

1. Connect equipment as shown in Fig. 1



2. With the polarity of the battery and the voltmeter connected as shown in Fig. 1, close the single pole battery switch. Note whether the needle of the instrument kicked up-scale and then returned to zero. If it did, the X_1 lead of the transformer's secondary winding is connected to the positive terminal of the voltmeter. When the battery switch is open, the needle will kick in the opposite direction.

3. Reconnect the transformer and apparatus as shown in Fig. 2. As you will note the oscilloscope is connected across the 220 volt 60 cycle input. Adjust the controls of the oscilloscope to obtain a sine wave pattern starting from zero and rising in a positive direction.

Check with your instructor at this point. Adjust the vertical gain until the two alternations of the sine wave are calibrated on the oscilloscope screen.

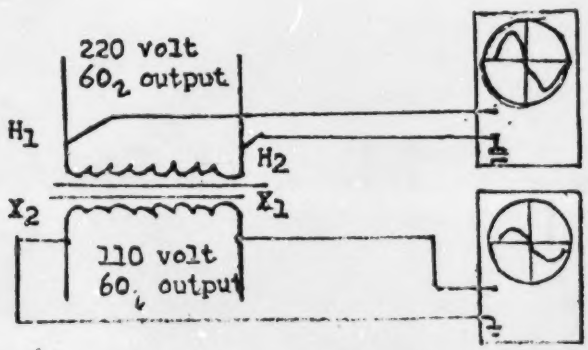


Fig. 2 to Determine Transformer Polarity Using The Oscilloscope

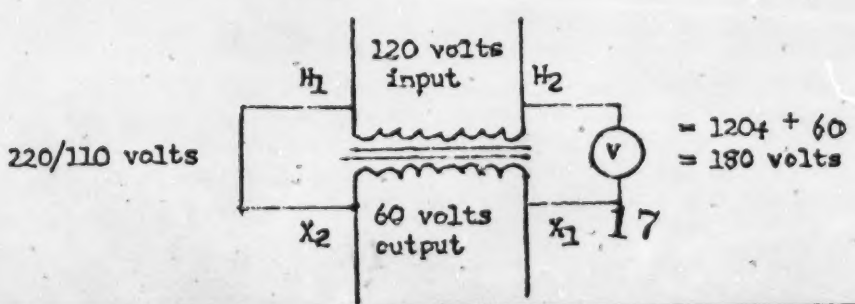
4. Without touching the oscilloscope controls, shift the connections of the oscilloscope to the secondary leads of the transformer and observe the pattern. If the screen trace rises from zero in a positive direction but is only half the magnitude of the original pattern, the ungrounded oscilloscope terminal is connected to the X_1 lead. If the pattern is reversed or 180 electrical degrees out of phase with the primary voltage pattern, then the ungrounded oscilloscope terminal is connected to the X_2 terminal.

5. Reconnect the transformer and apparatus as shown in Fig. 3. Instead of energizing the primary winding with 220 volts use 120 volts. The voltage induced on the secondary side will be only 60 volts.

6. If the transformer is of the polarity as shown in Figure 3, the voltmeter will indicate the sum of the primary and secondary voltages which will be approximately 180 volts. If the polarity of the secondary leads is opposite to what is shown in Fig. 3, the voltmeter will read the difference between the primary and secondary voltage value or 60 volts.

Fig. 3

Fig. 3. To Determine Transformer Polarity Using The A.C. Polarity Test Method.



7. From these three methods of testing, determine the polarity of the transformer.

8. Reconnect the transformer and apparatus as shown in Fig. 4.

Fig. 4

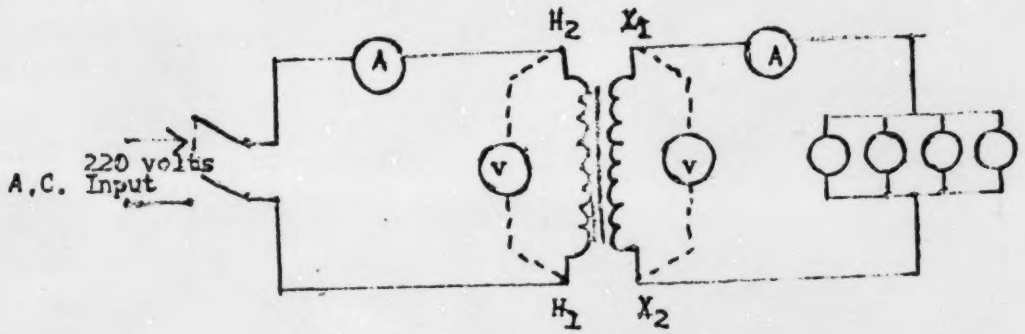


Fig. 4 For Ratio Test

9. Energize the 220 volt high voltage winding from a 220 volt source. Apply a load of 10 amperes to the 110 volt secondary winding.

10. Read and record the primary volts, primary amperes, secondary volts and secondary amperes. Observe the relationship between the primary and secondary volts and also the primary and secondary current values.

Observations

Jobs No.	Primary volts	Primary amperes	Secondary volts	Secondary amperes
1				

Calculations

1. Determine the ratio of step down of voltage for this transformer.

$$\text{Voltage Ratio} = \frac{\text{Primary Volts}}{\text{Secondary volts}}$$

2. Determine the current ratio between primary and secondary currents for this transformer.

$$\text{Current Ratio} = \frac{\text{Primary amperes}}{\text{Secondary amperes}}$$

Questions

1. From the polarity test made on the transformer used in this job determine whether it has additive or subtractive polarity.

2. Explain the relationship between the number of turns on the primary and secondary windings to the primary and secondary voltage values.

3. Explain the difference between an additive polarity and a subtractive polarity transformer.

4. Explain the relationship between the number of turns on the primary and secondary winding to the primary and secondary current values.

5. List the data that would be given on the nameplate of a typical distribution transformer.

References:

Duff, J. R., Alternating Current Fundamentals

Nadon & Gelm ine - Industrial Electricity - Lister, E. C. - Electric Circuits and Machines

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TRANSFORMERS

Job Sheet 3
Page 1 of 3

Connect Transformers in Parallel

Objective

To study the current and voltage relations as well as the connections for single phase transformers operating in parallel.

Materials Required

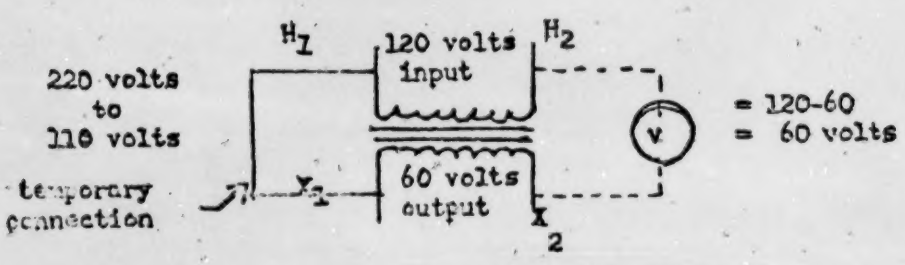
2 - single phase distribution transformers
1 - A.C. ammeter (0-30 amperes)
2 - A.C. voltmeters (0-150,300 volts)
2 - Ammeters (0-10,20 amperes)
1 - Lampbank
2 - Double-pole, single-throw knife switches

Explanation

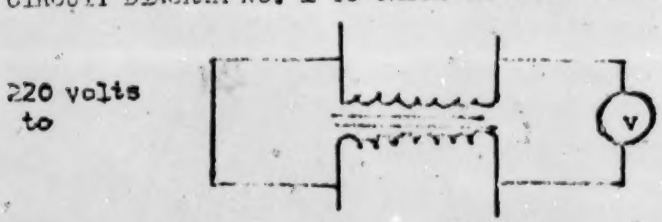
Transformers will operate satisfactorily in parallel with their high and low voltage winding respectively connected directly to the same circuits provided that they have (1) the same ratio of transformation, (2) the same voltage rating and (3) approximately the same regulation. If the low tension voltages are different, the transformer having the highest voltages will circulate current to those of lower voltage and cause a continuous loss. If transformers connected in parallel do not have the same regulation, they will not share the total load in proportion to their ratings. The greater share of the load will be taken by the transformer having the best regulation.

Procedure

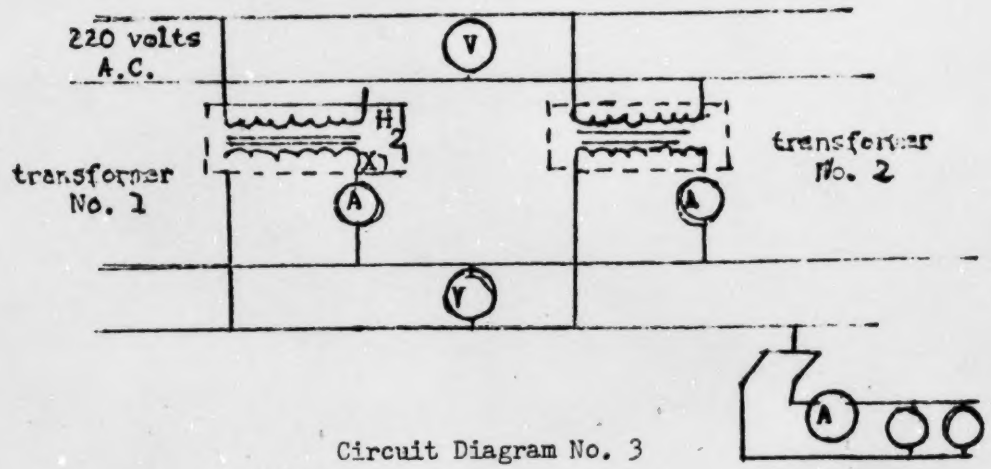
1. Test the polarity of each transformer, connect transformer as in diagrams 1 and 2.



CIRCUIT DIAGRAM NO. 1 TO CHECK TRANSFORMER POLARITY



2. Connect apparatus as shown in circuit diagram #3, be sure that only transformer secondary leads with the same subscript marking are connected to the same secondary bus bar.



Circuit Diagram No. 3

3. Load the transformers in four steps from 25% load to 100% load.

4. Read and record all instrument readings for each of the four load points.

	E_p	E_s	1 Sec No. 1	1 Sec No. 2	1 Sec Total
1					
2					
3					
4					

Questions

1. Is it possible to operate transformers with different KV.-A. capacities in parallel? If so what factors must be considered for successful operation?

2. What is meant by additive and subtractive polarity of transformers?

3. Describe the polarity test used for both additive and subtractive polarity transformers. Include diagrams to help clarify your answer.

References

Nadone and Gelmine - Industrial Electricity, Volume 2
Duff, J. R. - Alternating Current Fundamentals
Lister, E.C. - Electric Circuits and Machines
MiLeaf - Electricity 1-7

Job Sheet 4
Page 1 of 3

Connect Single Phase Transformers For 3 Wire System

Objective

To determine the voltage and current relations in a single phase three wire system fed from the secondary of a single phase distribution transformer.

Materials Required

1 - Single phase transformer with suitable secondary taps
1 - A.C. voltmeter (0-150-300 volts)
2 - A.C. ammeters (0-10, 20 amperes)
2 - A.C. ammeters (0-5-10 amperes)
2 - Single phase wattmeters (0-500-1000-2000 watts)
2 - Lampbanks use 130 volt lamps
1 - Double-pole single-throw knife switch

Explanation

Today the majority of new homes are wired for three wire service. Electric ranges are designed for three wire operation, therefore it is necessary to provide three wire service to homes which have electric ranges. In the home the three wires terminate at the distribution panel so that individual circuits carried through the house are at 115 volts, thus eliminating the dangers associated with 230 volt circuits.

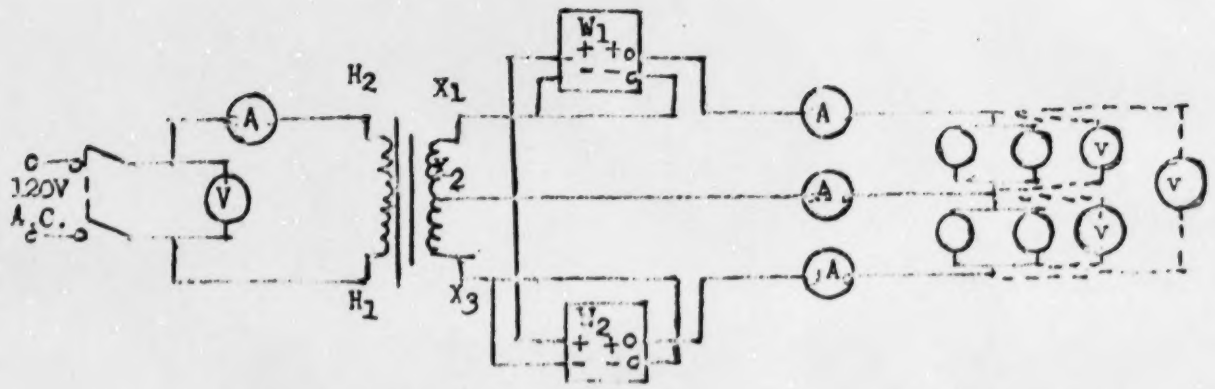
The double wound transformer is used as a source of three wire secondary distribution.

One of the important advantages of a transformer is its ability to provide a three wire circuit from the low voltage side. A 2300 primary 230/115 volt secondary step down transformer is a popular rating. This service is particularly advantageous in general distribution systems because it reduces the cost of copper feeders and it provides a method whereby the normal lighting circuits are supplied with 115 volt service, and the 230 volt service can be provided for the motor loads.

Procedure

1. Connect apparatus as shown in circuit diagram 1.

DIAGRAM 1



2. Have one lampbank take 8 amperes and the other take 10 amperes.
3. Read and record all values of voltage, current and wattage.
4. Open neutral wire and repeat step 3.
5. Close neutral and have the current taken by both lampbanks the same.
6. Read and record all values of voltage, current and wattage.

Observations

OBS No.	INPUT PRIMARY			Secondary Output							
	E	L	L	E_{L1+N}	E_{L2-N}	E_{L1-2}	I_{L_1}	I_{L_2}	I_N	Watts 1	Watts 2
1											
2											
3											

NOTE: Observation No. 1 with load unbalanced.
Observation No. 2 with load unbalanced and neutral open
Observation No. 3 with load balanced.

Calculations

OBS No.	1 Neutral	Watts Total	Total V	Total A
1				
2				
3				

Questions

1. Where is this type of transformer connection commonly used?

2. What effect has an unbalanced non-inductive load on the neutral of a single-phase three-wire system?

3. How does the current in the neutral wire compare with the current values in the other two conductors in this type of system?

4. What happens if the neutral wire of an unbalanced three-wire single-phase system accidentally becomes open circuited?

5. Why is the neutral wire of a single-phase three-wire system grounded?

References

Nadon & Gelmine - Industrial Electricity
Lister, E. C. - Electric Circuits and Machines

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TRANSFORMERS

Job Sheet 5
Page 1 of 1

Connect Single Phase Transformers in Series

Objective

To connect two single phase transformers in series.

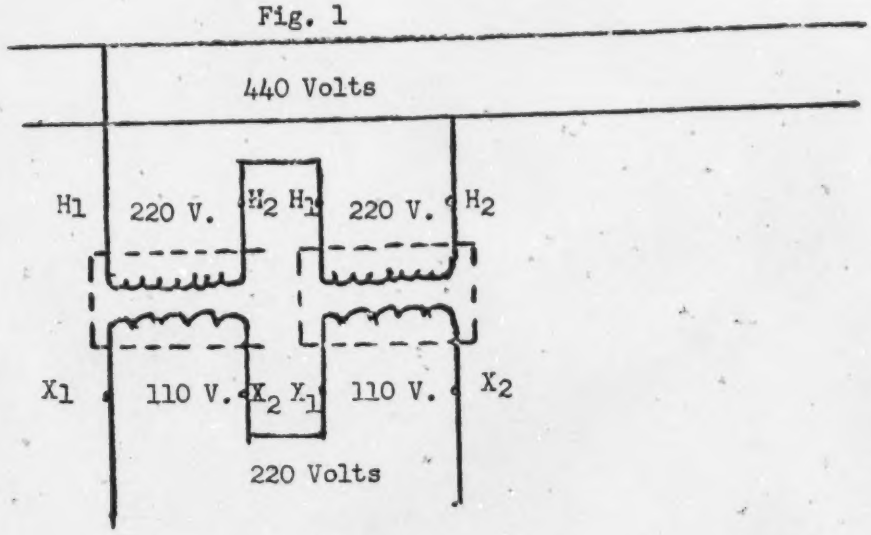
Materials Required

2 - Single phase transformers
2 - A.C. voltmeters (0-150-300 volts)

Procedure

1. Connect primary side of transformers as shown in Fig. 1.

Fig. 1



2. Connect secondary side of transformers as shown in Fig. 1
3. Secure permission from your instructor to energize the circuit.
4. Read and record voltages in primary and secondary circuits.
5. All readings should be recorded in suitable form.

References

Dawes, C. L. - Industrial Electricity Vol. 2
Croft, T. - American Electrician's Handbook
Seippel, Robert - Fundamentals of Electricity

Job Sheet 6
Page 1 of 4

Short Circuit Test on Transformers

Objective

To determine the efficiency of a transformer at various load points by the short circuit method or impedance method.

Materials

1 - Single phase 3 KVA 220/110 volt distribution transformer
1 - A.C. voltmeter (0-150-300 volts)
1 - A.C. voltmeter (0-10-20 volts)
1 - A.C. Ammeter (0-0.5 amperes)
1 - A.C. ammeter (0-20 amperes)
1 - Wattmeter 0-1000 watts
1 - Wattmeter 0-2000 watts
1 - Lampbank
1 - Double pole knife switch
1 - Switch
1 - Single pole knife switch

Procedure

1. To determine the core loss of the transformer, use the circuit connections in Fig. 1. Use a low reading ammeter and wattmeter to obtain accurate results.

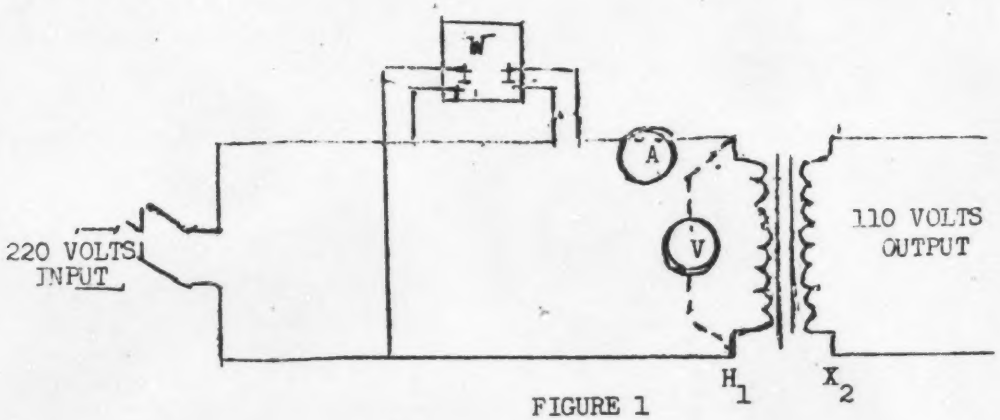


FIGURE 1

2. Read and record in Table 1 the voltage, the exciting current, and the watts core loss with the 220-volt side used as the primary winding.

CORE LOSS TEST
Table 1

NO.	PRIMARY VOLTS	EXCITING AMPERES	WATTS CORE LOSS	CONNECTION
1				PRIMARY 220 VOLT WINDING
2				PRIMARY 110 VOLT WINDING

3. Repeat the procedure in Step 2 with the 110 volt side used as the primary winding.
4. Perform the short circuit or impedance test, connect apparatus as shown in circuit diagram 2, using the 220-volt winding as the primary winding.

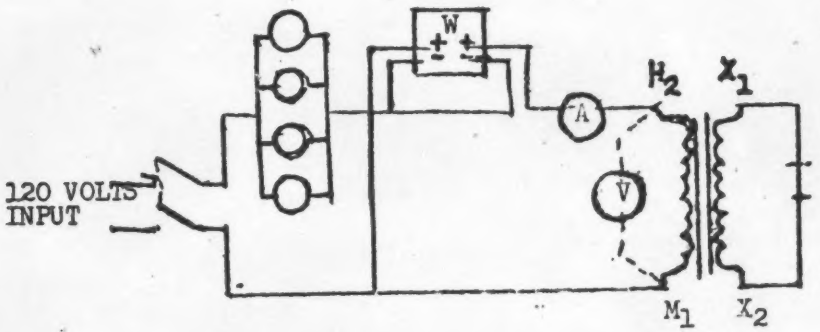


FIGURE 2 TO OBTAIN COPPER LOSS AND IMPEDANCE VOLTS

5. Close the short-circuiting switch on the secondary side. Next close the line switch and adjust the lamp load resistance until 25% of rated primary current is obtained.
6. Read and record in Table 2 the voltage, amperes, and watts. Please disconnect the voltmeter when reading the ammeter and wattmeter.

No	IMPEDANCE VOLTS	PRIMARY AMPERES	WATTS CU. LOSS	PERCENT LOAD
1				0 %
2				25 %
3				50 %
4				75 %
5				100 %
6				125 %

TABLE 2

7. Adjust the lamp bank resistance to obtain 50%, 75%, 100% and 125% of rated current. Read and record values of volts, amperes, and watts for each of these load points in Table 2. The actual impedance voltage will be obtained at 100% full load current.

	CORE LOSS	COPPER LOSSES	TOTAL LOSSES	WATTS OUTPUT	WATTS INPUT	PERCENT EFFICIENCY	PERCENT LOAD
1							0%
2							25%
3							50%
4							75%
5							100%
6							125%

Calculations

Total Losses = core loss + total copper losses =
WO + CU losses.

Watts Output = full load rating x per cent load

Watt Input = Watts output + total losses

Per cent Efficiency = $\frac{\text{watts output}}{\text{watts input}}$

Questions

1. What are the losses in a transformer? Explain.

2. What are the advantages in using the short circuit method to obtain the efficiency of a transformer?

3. What is meant by per cent impedance of a transformer?

4. Why do transformers have to be cooled? Give some common methods used in cooling transformers.

References

Gibbs, J. B. - Transformer Principle and Practice
Nadon and Gelmine, Industrial Electricity

Core Test on Transformers

Objective

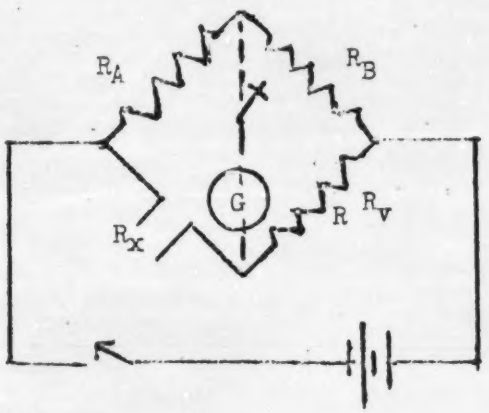
To determine the efficiency of a standard distribution transformer by the indirect method.

Materials Required

1 - Single-phase distribution type transformer
1 - A.C. voltmeter (0-150,300 volts)
1 - A.C. Ammeter (0-1 amperes)
1 - Wattmeter (0-150-300-600 watts)
1 - Single pole, single throw knife switch
1 - Double pole, single throw knife switch
1 - Wheatstone bridge
1 - Galvanometer

Procedure

1. Connect apparatus as shown in Fig. 1.



2. Measure resistance of high-voltage winding by means of the wheatstone bridge.
3. Measure resistance of the low-voltage winding by means of the wheatstone bridge.

Observation Table No. 1 - Resistance Measurement

OBS No.	$\frac{R_A}{R_B}$	R_V	R_X	WINDING
1				High side
2				Low side

4. Connect apparatus as shown in Fig. 2

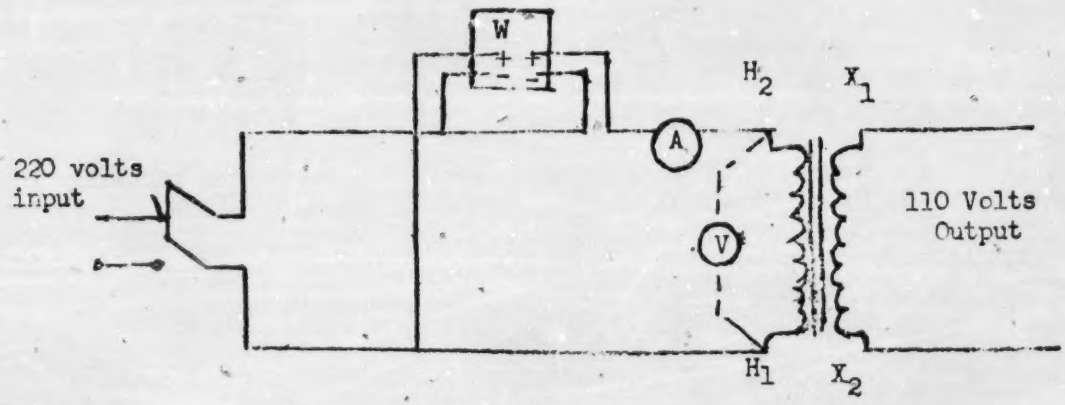


Figure 2 - Connections For Core Loss Test

5. Have your instructor check and approve the circuit connections.
6. Close main switch and read and record all instruments.
   Note: When reading ammeter and wattmeter, disconnect voltmeter.

Observation Table No. 2 - Core Loss Measurement

obs no.	primary volts	exciting amps	core loss in watts	connection
1				high side
2				low side

Calculations

obs no.	core loss	cu.loss h.v.s.	cu loss l.v.s	Total losses	watts output	watts input	percent eff.	percent load
1								25%
2								50%
3								75%
4								100%
5								125%

Sample Calculations

Using Observation No. 1 in Observation Table No. 1

$$R_X = \frac{R_A}{R_B} \text{ RV} \qquad \text{R Effective} = R_X \times 1.2$$

Using either Observation No. 1 or No. 2 in Observation Table No. 2.

Core Loss Equals _____ Watts as Read from Wattmeter

Copper Loss - Primary Winding

$$\text{Watts} = I_P^2 \times R_P$$

Copper Loss - Secondary Winding

$$\text{Watts} = I_S^2 \times R_S$$

Total Losses

Watts = Cu Loss Primary + Cu Loss Secondary + Core Loss

Total Output

Watts = E x I x P.F.

Total Input

Watts = Watts Ouptu + Total Copper Losses + Copper Loss

Efficiency

$$\text{Per cent Efficiency} = \frac{\text{Watts Output}}{\text{Watts Input}} \times 100$$

References

Dawes, C. L. - Industrial Electricity, Vol. 2
Nadon and Gelmine - Industrial Electricity

Questions

1. Why is it possible to accurately measure the efficiency of a transformer by measuring the power input and power output with two wattmeters?

2. Why is the percent efficiency of a transformer relatively high?

3. What effect is there on a transformer when operated on a circuit below its rated frequency?

4. Does the nameplate rating of a transformer have reference to the input or output?

Two Phase Transformer Scott Connection

Objective

To connect two single phase transformers in a scott connection for two phase.

Materials Required

2 - Single Phase transformers with special taps on the secondary winding
2 - A. C. voltmeters (0-150-300 volts)

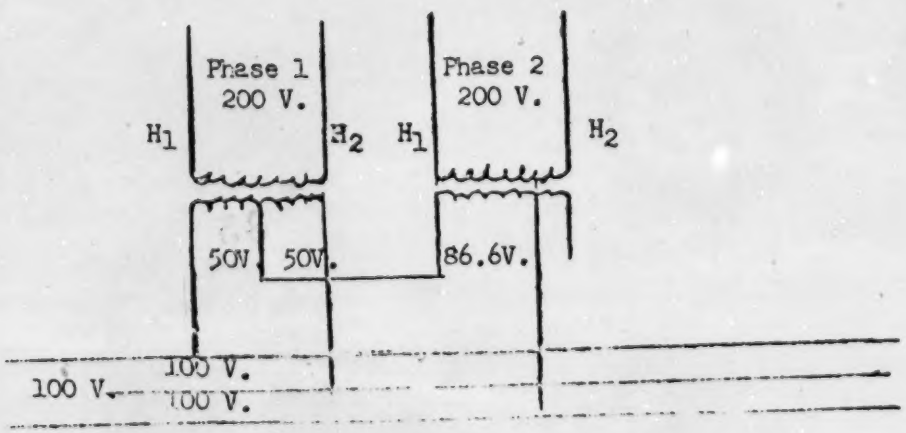
Explanation

By means of this connection often called the "Teaser" connection, two like transformers can be used to transform from three phase to three phase, and also from two phase to three phase, or from three phase to two phase. Fig. 1 shows the connections and secondary coil voltages, for a two-phase to three phase transformation. Note here that the teaser winding is tapped so that only 86.6 per cent of its turns are in the circuit as shown. It also may be noted that the voltage on the teaser transformer is only 86.6 per cent of the three phase line voltage.

Procedure

1. Connect primary windings of the two transformers as shown in Fig. 1.

Fig. 1



2. Connect secondary windings of the two transformers as shown in Fig. 1.
3. Secure permission from your instructor to energize the circuit.
4. Read and record the voltages on both the primary and secondary sides of the transformers.
5. All readings should be recorded in suitable form acceptable to your instructor.

References

Timbie, W. H. - Wilson, F. G. - Industrial Electricity Vol. 2
Croft, T. - American Electrician's Handbook
Mileaf - Electricity 1-7

Three Phase Connections

Objective

To acquaint the student with different three phase connections used in transformer work.

Explanation

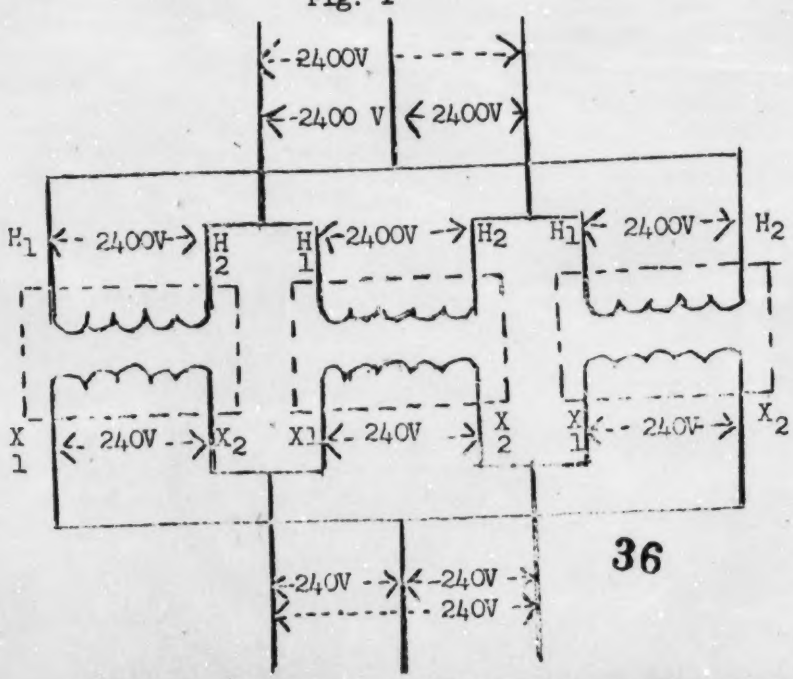
Electrical energy is usually generated by 3-phase alternating-current generators. Likewise, 3-phase systems are used for the transmission and distribution of electrical energy. It is often necessary to transform the voltage on these 3-phase systems. In some applications the voltage is transformed to a higher value; in other applications, to a lower value.

Transformers are usually connected in banks of three single phase transformers for use on three phase circuits. They are usually connected in any of four standard ways; the delta - delta, the wye - wye, the delta-wye, and wye-delta. There is also the open delta (or V) connection whereby it is possible to transform voltages on a three phase system by means of two single phase transformers.

The Delta Connection

If three single-phase transformers rated 2400-240 volts are to be used to step-down 2400 volts three phase to 240 volts three phase, a closed-delta connection is used. Fig. 1 illustrates the connections for three single phase transformers with their primary and secondary windings connected in delta, where 2400 volts three-phase is to be stepped down to 240 volts, three phase.

Fig. 1



In any closed delta transformer connection two important facts must be kept in mind. (a) The line voltage and the voltage across the transformer windings are the same. A study of any delta connection shows that each transformer coil winding is connected directly across two line leads. Therefore, the line voltage and transformer coil winding voltage must be the same.

(b) The line current is greater than the coil winding current in a delta-connected transformer bank. The line current is equal to 1.73 x coil current. A study of a closed delta transformer connection will show that each line lead is fed by two transformer coil currents which are out of phase. Because the two coil currents are out of phase they do not add directly together.

The Open Delta Connection

A three phase transformation of energy is possible using only two transformers.

This is called an open delta or V connection.

The open delta connection is often used in an emergency where one of the three transformers in a delta-delta bank becomes defective. Many times it is imperative that a consumer's three phase power supply be restored as soon as possible. This can be done if the defective transformer is cut out of service. A typical case where this type of connection could apply is as follows:
(a) Three 50 K.V.A. transformers, each rated at 2400 volts on the high voltage winding and 240 volts on the low-voltage winding, are banked in a delta-delta connection. This closed-delta bank is used to step down 2400 volts, three phase, to 240 volts, three phase to supply the industrial power user.

(b) There is a power failure caused by one of the transformers being damaged by lightning. The three phase power service must be restored at once.

Fig. 2 shows how this is accomplished. The student will note that transformer 3 is the defective transformer. By disconnecting all leads of this transformer the closed delta bank becomes an open delta bank.

Fig. 2

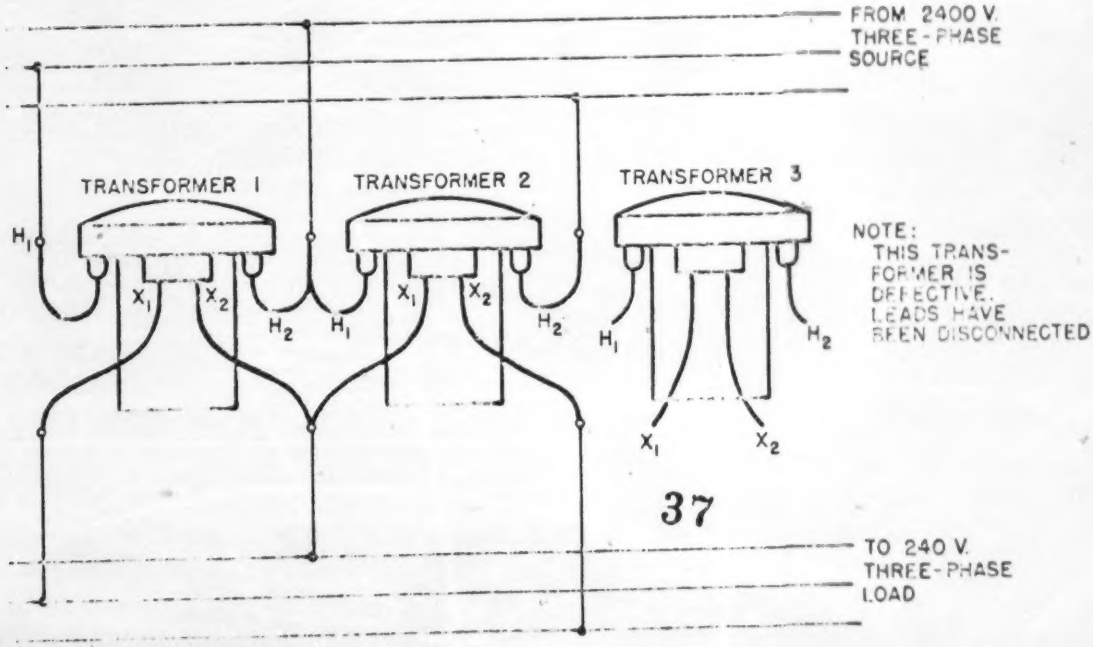
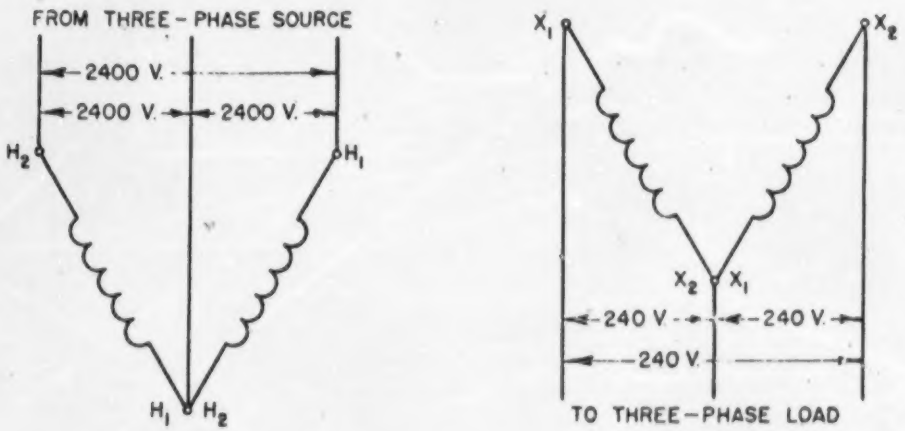


Fig. 3 illustrates a schematic diagram of this same open delta connection. It will be noted that with one transformer removed the triangular coil arrangement is open on one side. Therefore this connection is called an open-delta connection. Also because this schematic diagram connection resembles the letter V it is sometimes called the V connection.

Fig. 3



At first it might appear that the open delta bank would have a total K.V.A. capacity of two-thirds that of a closed delta bank. However in actual practice the K.V.A. rating of an open delta bank is only 58% of the capacity of a closed delta bank. The reason for this is that the currents of the two transformers in this open delta connection are out of phase. This results in the total available capacity of the open delta bank being only 58% and not 66.7%.

The Wye Connection

If three single phase coils are so arranged that all the coils ends are connected together, a simple WYE system is formed.

Fig. 4

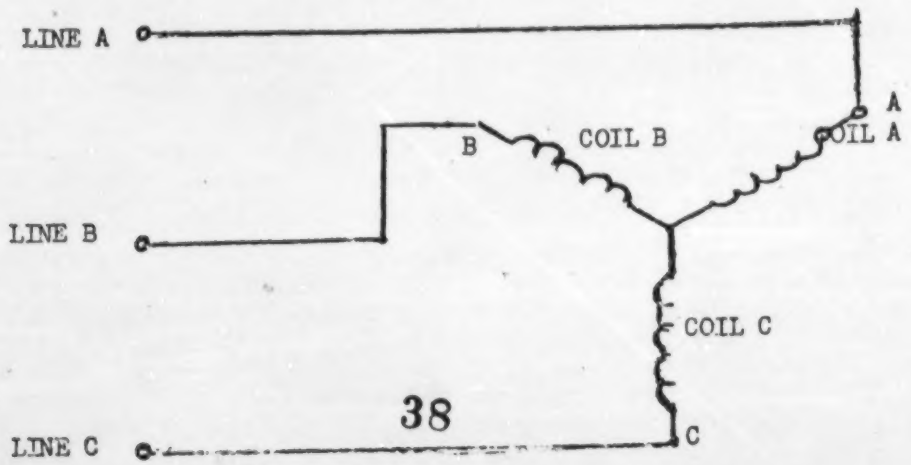
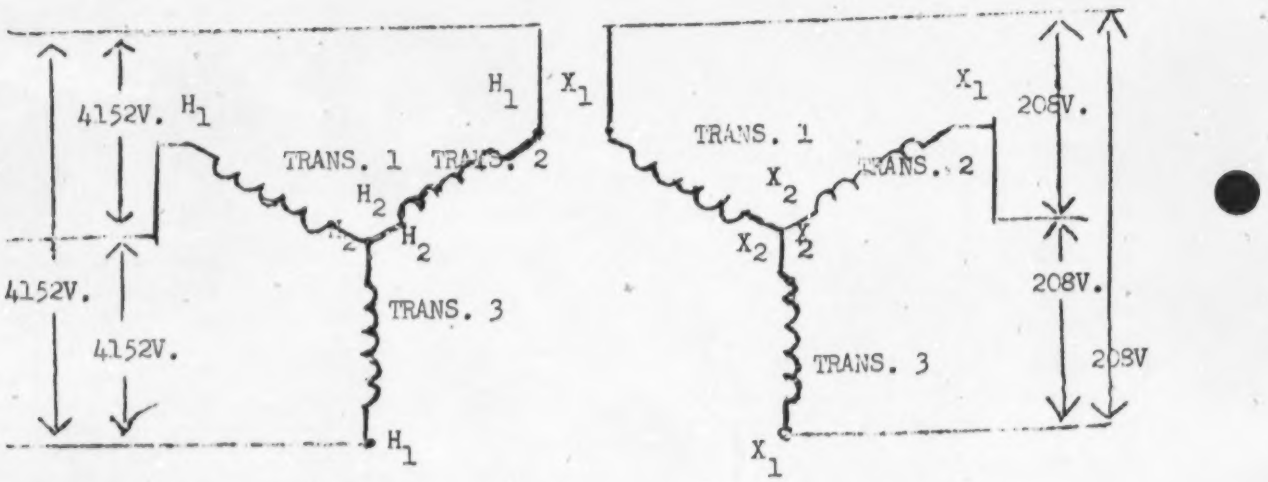


Figure 4 illustrates the basic Wye connection. The three coils are marked coil A, coil B, and coil C, the ends of the three coils are marked O while the beginnings are marked A, B, and C. It will be noted that each of the three coil beginnings are connected to line leads which feed to a three phase system.

If three single phase transformers are used to step down 4152 volts, three phase to 208 volts three-phase, a wye-wye connection is used. Each of the three transformers would be rated 2400 volts on the high voltage windings and 120 volts on the low voltage winding.

Fig. 5 illustrates this wye-wye connection. The H_2 leads or primary winding ends are connected together. The beginning or H_1 lead of each transformer is connected to one of the three line leads. This connection when developed as a schematic diagram, resembles the letter Y which is written WYE.

Fig. 5



Four Wire Wye Connection

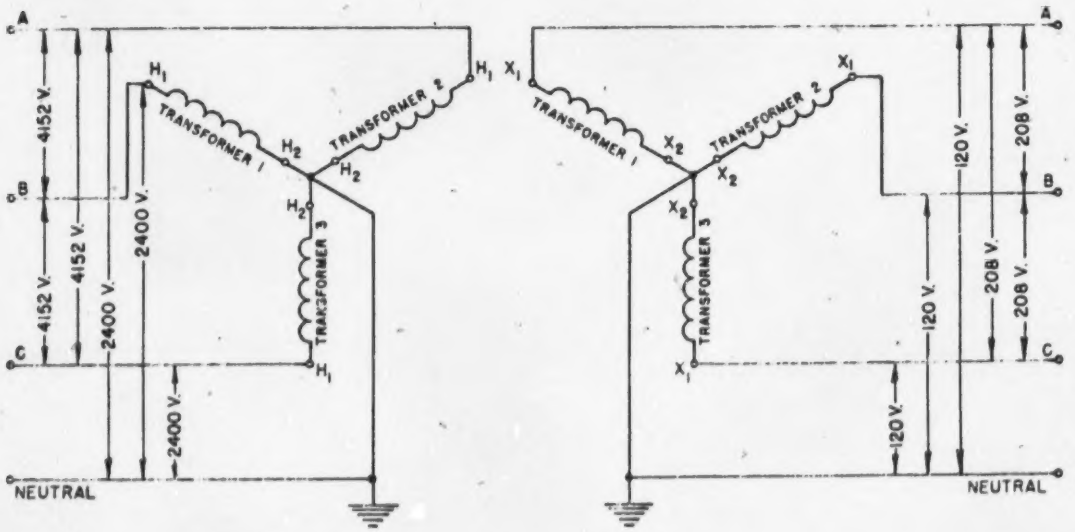
Fig. 6 illustrates a Wye-Wye connection of a transformer bank. In this connection diagram, a three-phase four wire system is used to feed the three phase high voltage input to the transformer bank. The neutral wire is connected to the common point where all three high voltage primary winding ends or H_2 leads terminate. The voltage from the neutral to any one of the three line wires is 2400 volts. Each high voltage winding is connected between the neutral and one of the primary windings. The voltage across the three line leads is 1.73 x 2400 volts or 4152 volts. The neutral wire maintains a relatively constant voltage across each of the high-voltage primary windings even though the load is unbalanced. This neutral wire is grounded. Therefore, it protects the three high-voltage primary windings from lightning surge conditions.

A three-phase, four wire system feeds from the low-voltage secondary side of the transformer bank to the load. Each low voltage secondary winding is connected between the neutral and one of the three line leads. The voltage output of each secondary winding is 120 volts. Fig. 6 shows that the voltage between the neutral and any one of the three line leads on the secondary side is 120 volts. The voltage across the three line leads is 1.73 x 120 volts or 208 volts. By using a three phase four wire secondary there are two voltages available for different types of load.

1. There is 208 volts available for three phase industrial power load such as three phase motors.

2. The use of a neutral wire makes it possible to also have 120 volts for lighting loads. This neutral wire is grounded. Therefore it protects the three low-voltage secondary windings from lightning surge connections.

Fig. 6



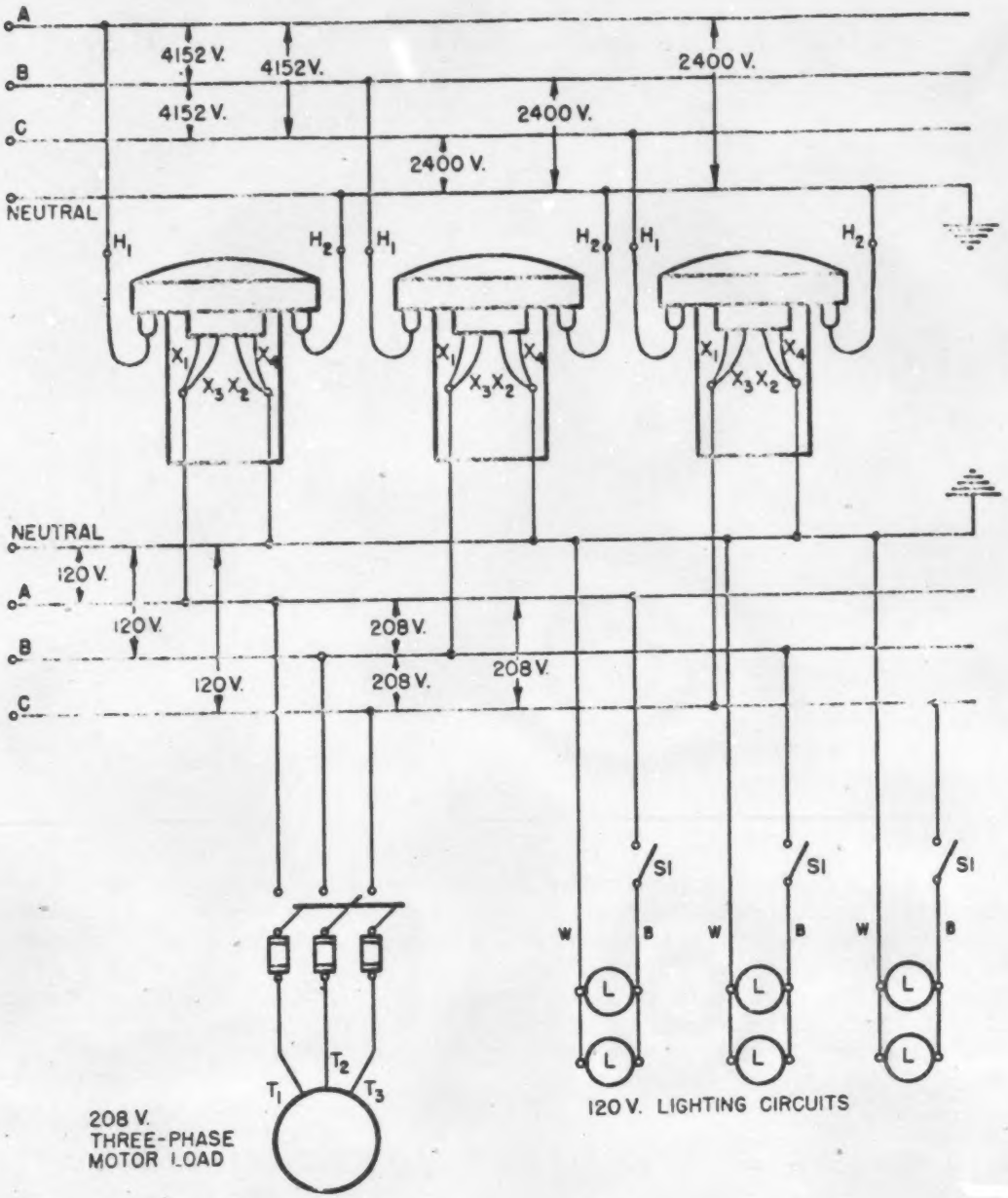
WYE-WYE TRANSFORMER BANK WITH NEUTRAL CONNECTION

Figure 7 illustrates three single-phase transformers connected as a Wye-Wye bank. Each transformer has two 120 volts low-voltage windings. In this connection diagram the two low voltage coils of each transformer are connected in parallel. This gives a voltage output of 120 volts for each single phase transformer. A check of the secondary connections show that the three transformers have their output windings connected in Wye. By having a three phase four wire secondary system two different types of services are available.

1. Three-phase 208 volts service for motor load.

2. Single-phase 120 volt service for lighting load.

Fig. 7



208 V
Three-Phase
Motor Load

120 V. LIGHTING CIRCUITS

FIG. 7 WYE-WYE TRANSFORMER BANK CONNECTIONS

Open Delta to Open Delta

Objective

To connect two transformers in a three phase open delta connection on both primary and secondary windings.

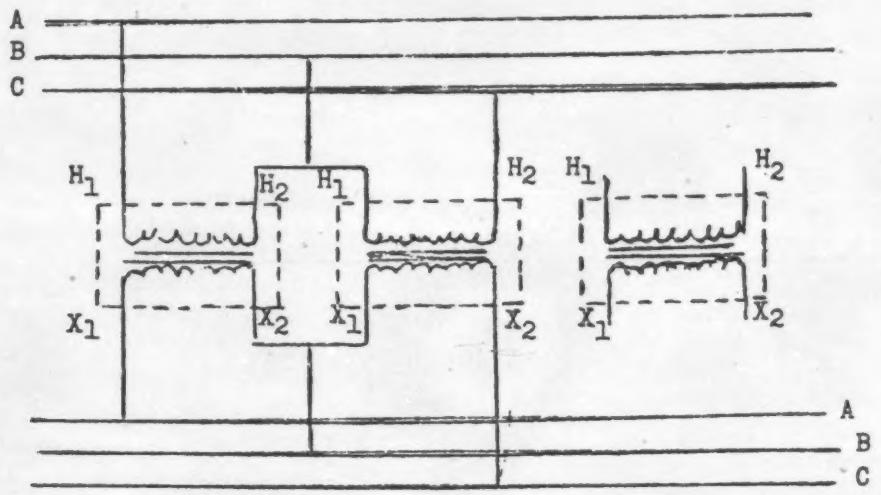
Materials Required

2 - Single phase transformers
2 - A.C. voltmeters (0 - 150 - 300 volts)

Procedure

1. Connect the primary windings of the two transformers as shown in Fig. 1.

Fig. 1



OPEN DELTA CONNECTION

2. Connect secondary side of transformer windings as shown in Fig. 1.
3. Read and record primary line and primary winding voltage valves. Also read and record secondary line and secondary winding voltage values.

Observations

OBS NO.	primary line volts			primary coil volts		secondary coil volts		secondary line volts		
	AB	BC	CA	1	2	1	2	AB	BC	CA
1										

References

Dawes, C. L. - Industrial Electricity Vol. 2
Nadon and Gelmine - Industrial Electricity

Questions

1. State an advantage of an open delta connection.
2. State a disadvantage of an open delta connection.

Job Sheet 9-B
Page 1 of 2

Closed Delta to Closed Delta

Objective

To connect three single phase transformers in a three phase closed delta primary and a three phase closed delta secondary.

Materials Required

3 - Single phase transformers
2 - A.C. voltmeters (0-150-300 volts)

Procedure

1. Connect the primary windings of the three transformers as shown in Figure 1.

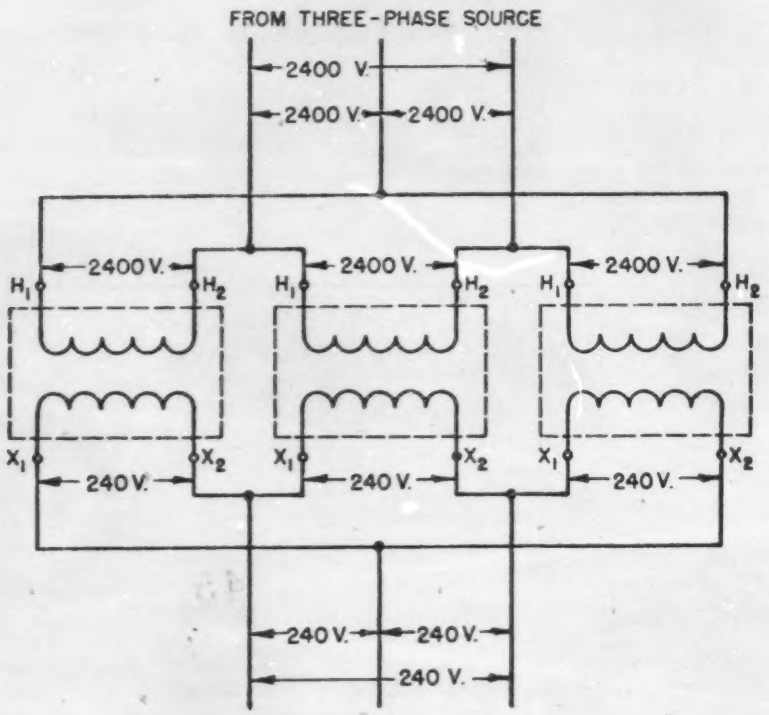


Fig. 1 - Delta-Delta Connection

2. Connect secondary side of the transformer windings as shown in Figure 1.

3. Read and record primary line and primary windings voltage values. Also read and record secondary line and secondary winding voltage values.

Observations

OBS NO	primary line volts			primary coil volts			secondary coil volts			secondary line volts					
	AB	BC	CA	1	2	3	1	2	3	AB	BC	CA			
1															

References

Dawes, C.L. - Industrial Electricity Vol. 2
Nadon and Gelmine - Industrial Electricity

Questions

1. What is one advantage in using a delta-delta connected transformer bank?

2. Give one practical application where single-phase transformers are connected in a delta-delta connection.

CONNECTICUT STATE VOCATIONAL SCHOOLS

TRANSFORMERS

Job Sheet 9-C
Page 1 of 1

Open Delta to Open Delta 4 Wire

Objective

To connect two single phase transformers open delta primary 3 wire to open delta secondary 4 wire.

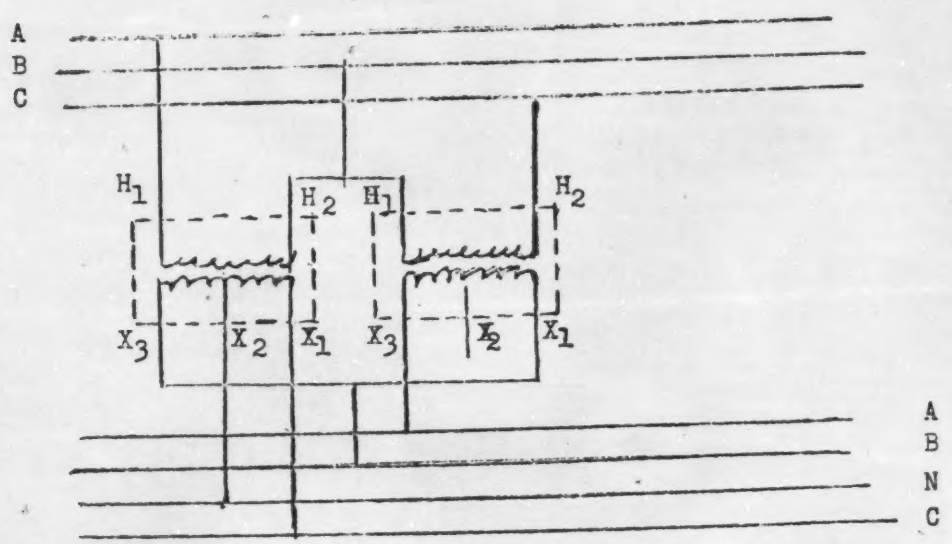
Materials Required

2 - Single phase transformers with suitably tapped secondary windings
2 - A.C. voltmeters (0-150-300 volts)

Procedure

1. Connect primary side of single phase transformers as shown in Fig. 1.

Fig. 1



2. Connect secondary side of transformers as shown in Fig. 1.
3. Check with your instructor for permission to energize circuit.
4. Read voltages on primary and secondary sides of transformers and record in suitable form.

References

Dawes, C.L. - Industrial Electricity Vol. 2
Croft, T. - American Electricians' Handbook

CONNECTICUT STATE VOCATIONAL SCHOOLS

TRANSFORMERS

Job Sheet 9-D
Page 1 of 2

Closed Delta to Closed Delta 4 Wire

Objective

To connect three single phase transformers in a three phase, closed delta 3 wire primary and a closed delta 4 wire secondary.

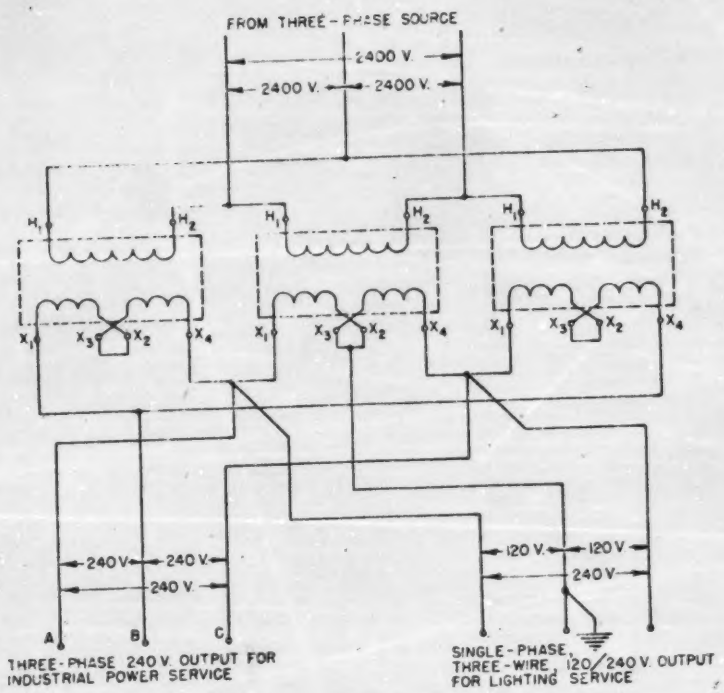
Materials Required

3 - Single phase transformers with center tapped secondaries
2 - A.C. voltmeters (0-150-300 volts)

Procedure

1. Connect primary side of transformers as shown in Fig. 1.

Fig. 1



2. Connect secondary side of transformers as shown in Fig. 1.
3. Secure permission from your instructor to energize circuit.
4. Read and record voltage readings on primary and secondary sides. Data should be recorded in suitable form.

References

Dawes, C.L. - Industrial Electricity, Vol 2.
Croft, T. - American Electricians' Handbook

Questions

1. State one practical application where single phase transformers are connected in a delta-delta connection, 4 wire secondary.

2. What is the advantage of having transformers connected in this manner?

T Connection to T Connection 4 Wire

Objective

To connect two single phase transformers in a T connected Primary and a T connected 4 wire secondary.

Materials Required

2 - Single phase transformers with suitable taps for use in T or Scott connection
2 - A.C. Voltmeters (0-150-300 volts)

Explanation

By means of a Scott or T connection and often called a "Teaser" connection, two like transformers can be used to transform from three phase to three phase, and also two phase to three phase, or from three phase to two phase.

Two transformers are used, having primaries a d and b c, and secondaries a' d' and b' c'. The middle point d of the winding b c must be accessible. One end d of the primary winding a d is connected to the middle point d of the primary winding b c. The ends of the three primary coils are connected to the three phase supply ABC as shown in Fig. 1 except that terminal a rather than a_1 is first connected to wire A. The transformer b c is called the main transformer and the transformer a d the teaser transformer.

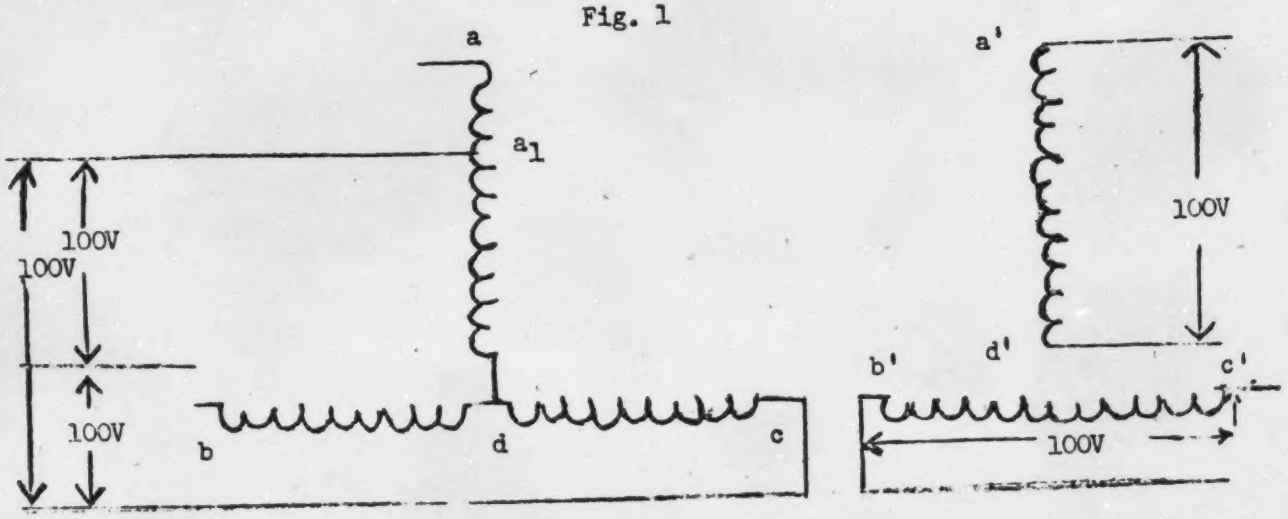
The three phase supply is assumed to have a line voltage of 100 volts, and the transformers have a 1-to-1 ratio. Usually, the ratio is other than 1-to-1, but this ratio has been chosen to illustrate the principle. Obviously, the principle can be applied to any ratio of transformation.

The voltages E_{dc} and E_{db} are each equal to 50 volts and differ in phase by 180, Fig. 1, since coil dc and db are both on the same magnetic circuit. Since the total voltage impressed across any system must be equal to the phasor sum of the component voltages, the three component voltages E_{da}, E_{db}, E_{dc} must combine in such a way as to give the three three-phase line voltages E_{ab}, E_{bc}, E_{ca}. In order that these component voltages may combine to give the three-phase line voltages, voltage E_{da} must be equal to 100 3/2, or 86.6 volts; and it must differ in phase from E_{db} and E_{dc} by 90. Hence a two-phase system is obtainable from the secondaries.

Since the voltage across transformer a d is 86.6 volts, its secondary voltage will be only 86.6 volts, whereas the voltage across b' c', the secondary of transformer b c is 100 volts. This gives two different voltages in the two phase of the two-phase secondary system, which is undesirable. By connecting

line conductor A to a_1, a tap which makes E_{ald} = 0.866E, the volts per turn in transformers a d are increased in the ratio of 1 to 0.866. That is, a_1d is now a step-up transformer having a ratio of 0.866 to 1. The secondary voltage $E_{a'\ d'}$ will now be 100 volts, which gives a symmetrical two-phase system. The tap a_1 is called the Scott tap.

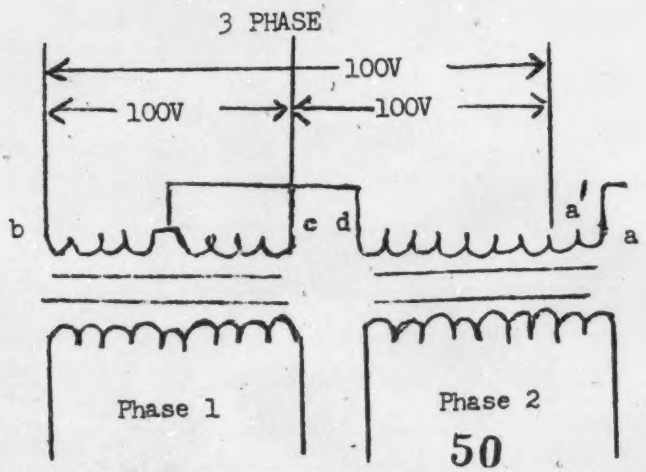
Fig. 1



Procedure

1. Connect the primary winding of the two transformers as shown in Fig. 2.
2. Connect the secondaries of the two transformers as shown in Fig. 2.

Fig. 2



3. Check with your instructor and secure permission to energize transformers.
4. Read and record voltages in both primary and secondary sides of the transformers.

References

Gibbs, J. B. - Transformer Principles and Practice
Timbie, W. H. - Industrial Electricity

Questions

1. Why is one of the transformers used in this job called the teaser transformer?
2. How does the teaser transformer differ from the other transformer used in this job?
3. State the disadvantages of a T connected transformer.

Wye to Wye

Objective

To connect three transformers in a three phase Wye connected primary and a three phase Wye connected secondary.

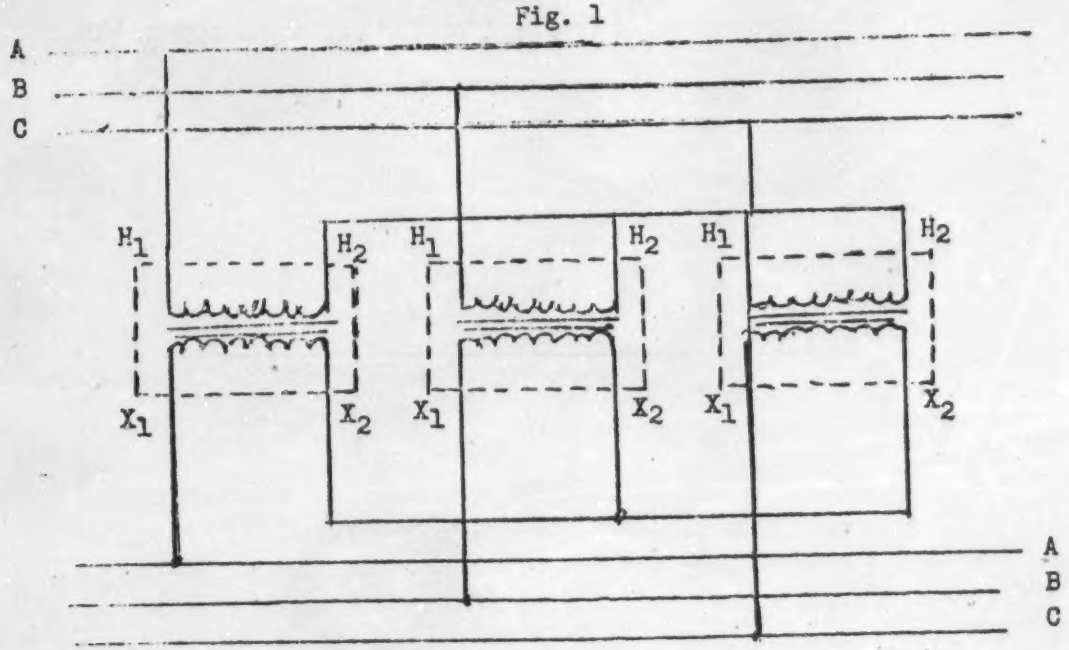
Materials Required

3 - Single phase transformers
2 - A.C. voltmeters (0-150-300 volts)

Procedure

1. Connect the primary windings of the three single phase transformers as shown in Fig. 1.

Fig. 1



2. Connect secondary side of transformer windings as shown in Fig. 1.
3. Read and record primary line and primary winding voltage values. Also read and record secondary line and secondary windings voltage values.

Observations

References

Dawes, C.L. - Industrial Electricity
Nadon and Gelmine - Industrial Electricity

Questions

1. State the advantage of connecting three single phase transformers in WYE.
2. State the disadvantages of having transformers connected in WYE.
3. State the advantages of having transformers connected in WYE.

CONNECTICUT STATE VOCATIONAL SCHOOLS

TRANSFORMERS

Job Sheet 9-G
Page 1 of 2

Delta 3 Wire to Wye 4 Wire

Objective

To connect three transformers in a three phase delta connected primary 3 wire and a three phase 4 wire Wye connected secondary.

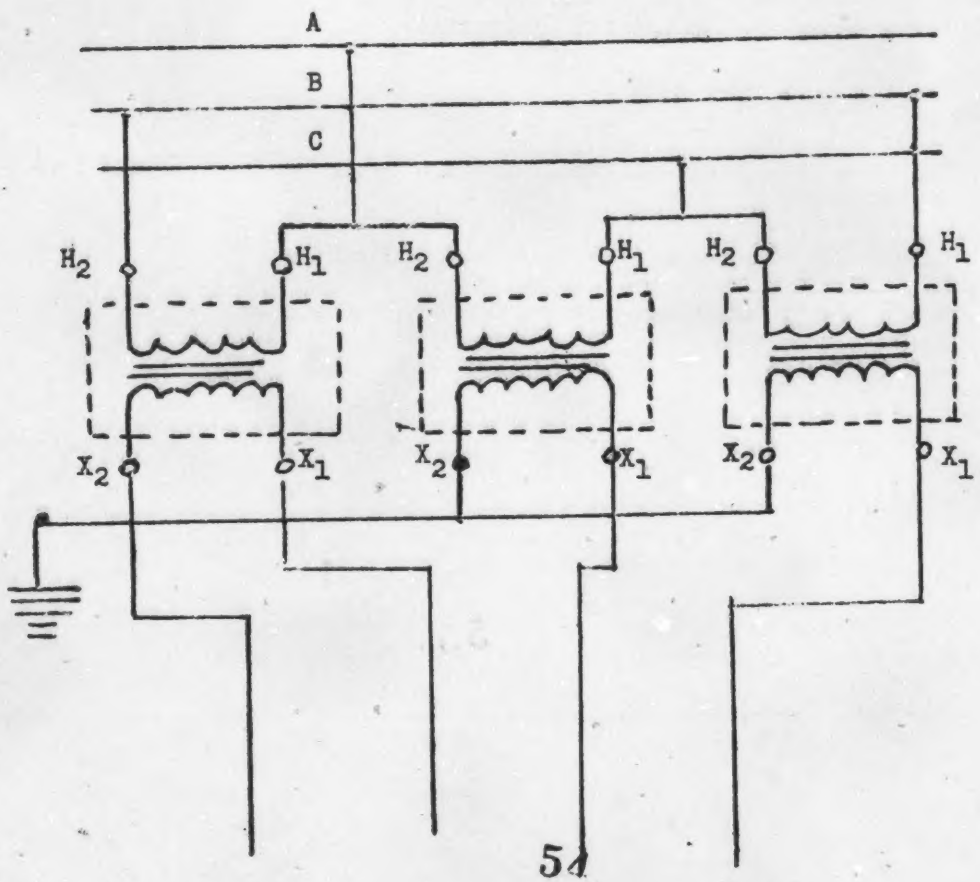
Materials Required

3 - Single phase transformers
2 - A.C. voltmeters (0-150-300 volts)

Procedure

1. Connect the primary windings of the three single phase transformers into a three phase delta 3 wire connection.

Fig. 1



2. Connect secondary side of the three single phase transformers as shown in Fig. 1 into a three phase 4 wire Wye connection.

3. Read and record primary line and primary winding voltage values. Also read and record secondary line and secondary winding voltage values.

Observations

References

Dawes, C. L. - Industrial Electricity, Vol. 2
Nadon and Gelmine - Industrial Electricity

Questions

1. Give two practical applications for a delta-wye transformer bank connection.

2. State the advantages of a delta-wye connection.

3. State the disadvantages of a delta-wye connection.

Job Sheet 9-H
Page 1 of 2

Wye to Delta

Objective

To connect three single phase transformers into a three phase Wye connected primary, and a three phase delta connected secondary.

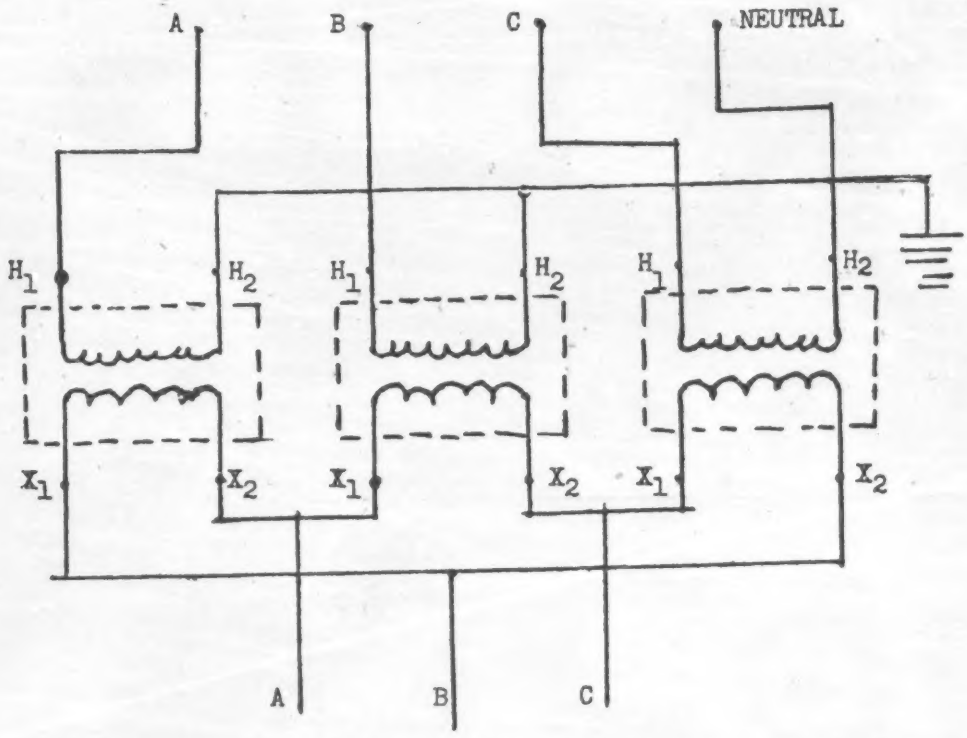
Required Materials

3 - Single phase transformers
2 - A.C. Voltmeters (0-150-300 volts)

Procedure

1. Connect the primary windings of the three transformers into a three phase Wye connection as shown in Fig. 1.

Fig. 1



2. Connect secondary side of transformer windings into a 3 wire three phase delta connection as shown in Fig. 1.
3. Read and record primary line and primary winding voltage values. Also read and record secondary line and secondary winding voltage values.

Observations

References

Dawes, C.L. - Industrial Electricity, Vol. 2.
Nadon and Gelmine - Industrial Electricity

Questions

1. State one practical application for a three phase Wye-delta transformer bank.

2. State an advantage of connecting transformers in a Wye-delta transformer bank.

CONNECTICUT STATE VOCATIONAL SCHOOLS

TRANSFORMERS

Job Sheet 9-I
Page 1 of 2

Grounding of Electrical Equipment (Auto Transformer)

Objective

To have student properly connect auto transformer and understand the proper method used in grounding.

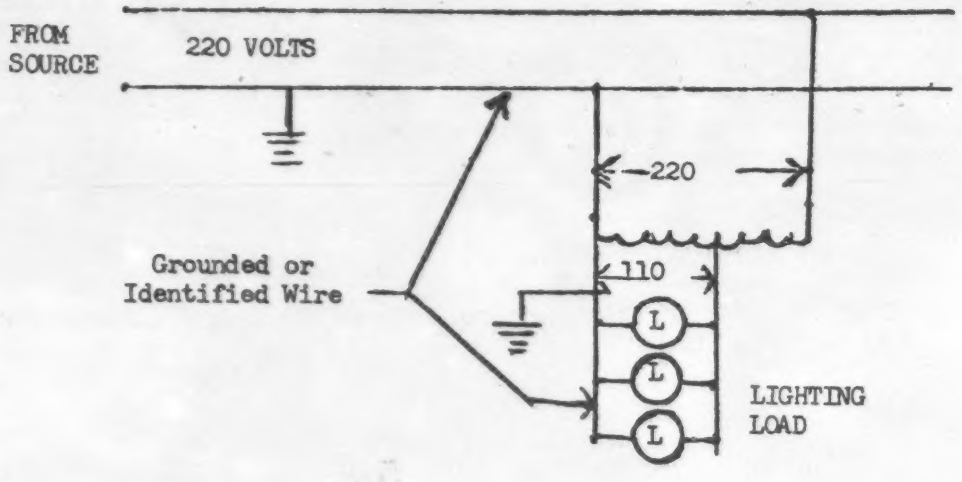
Materials Required

1 - Autotransformer
2 - Lamp banks

Explanation

It will be recalled that an autotransformer does not have separate primary and secondary windings. It consists of only one winding wound on an iron core. Part of the single winding of an autotransformer is common to both the primary and secondary circuits. For this reason Section 200-4 of the N.E.C. limits the use of an autotransformer for feeding branch circuits. The autotransformer may only be used where the identified ground wire of the load circuit is solidly connected to the ground wire of the source, as shown in Fig. 1.

Fig. 1



Procedure

1. Connect apparatus as shown in Fig. 2
2. Identify grounded conductor from source.

3. Select proper point on autotransformer for grounding as shown in Fig. 2.

4. After apparatus has been properly connected and grounded check with your instructor before energizing.

Fig. 2

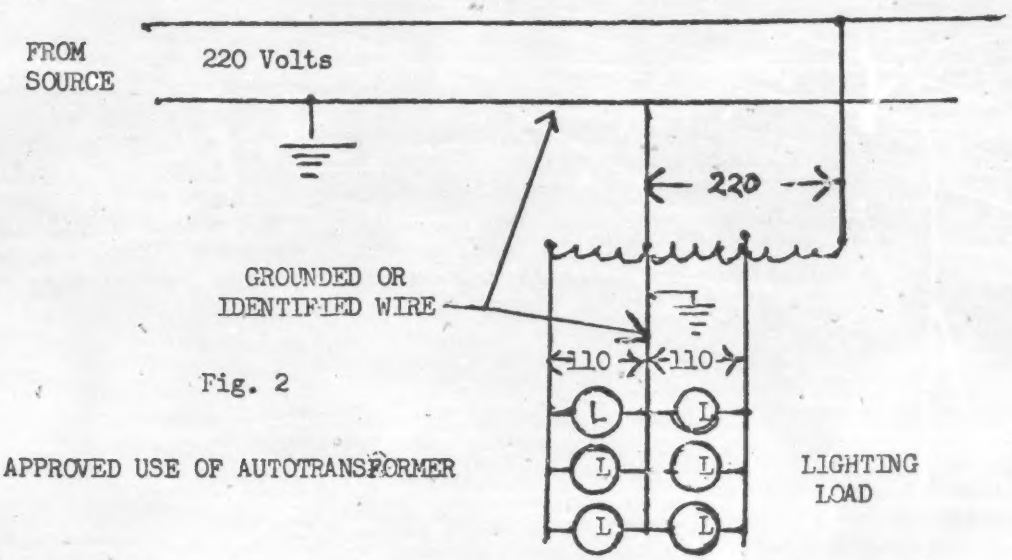


Fig. 2

APPROVED USE OF AUTOTRANSFORMER

References

Duff - Alternating Current Fundamentals
National Electrical Code

Questions

1. State the advantage of the use of an autotransformer.

2. State the N.E.C. rules as they apply to the use of autotransformers on lighting circuits.